Integration of Biomass into Gas Fired Combined Cycle - Thermodynamic and Economical Analyses

Enel Produzione

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Objectives

- Reduction of CO_2 emission to achieve Kyoto protocol commitment
  - EU target: - 8 %
  - Italy target: - 6.5 %
- Economical benefits from power generation through renewable sources

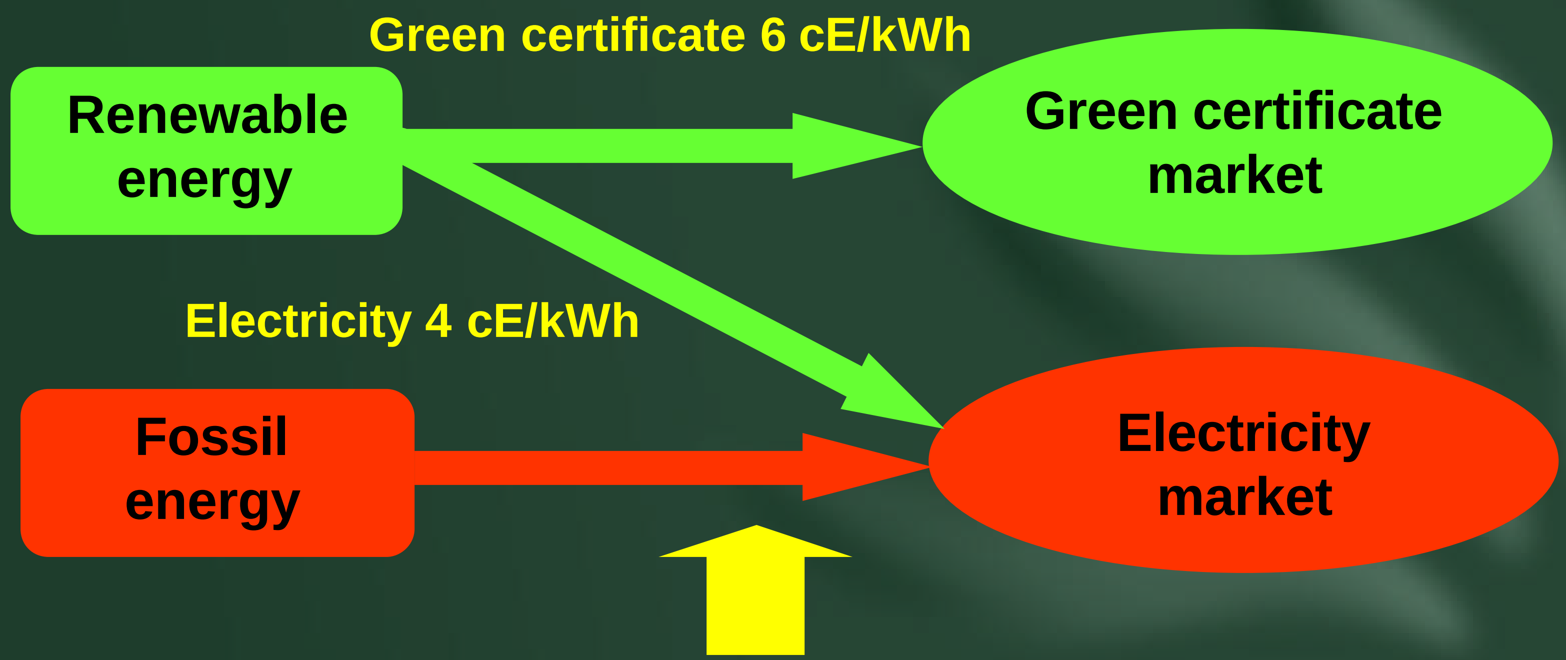
Reduction of CO_2 emission

- Improvement of energy conversion efficiency
- Adoption of lower carbon content fuels (Natural Gas)
- Power generation from renewable sources
- CO_2 capture and storage in fossil fuel power generating plants

Economic benefits from renewable sources

ITALIAN SITUATION

Renewable sources promotion on competitive base



Utility must generate at least 2% of total electricity from new renewable source plants

Biomass energetic conversion

Process	*Thermal Cycle*	*Efficiency*
Combustion	Stand alone Steam Cycles	25%
	Co-firing in Steam Power Plants	35%
Gasification	Stand alone Combined Cycles	32%
	Stand alone Steam Cycles	25%
	Co-firing in GT-CC	44%
	Additional firing in HRSG-CC	35%
Pyrolysis	Reciprocating Engines	30%

Integration of Biomass in Combined Cycles

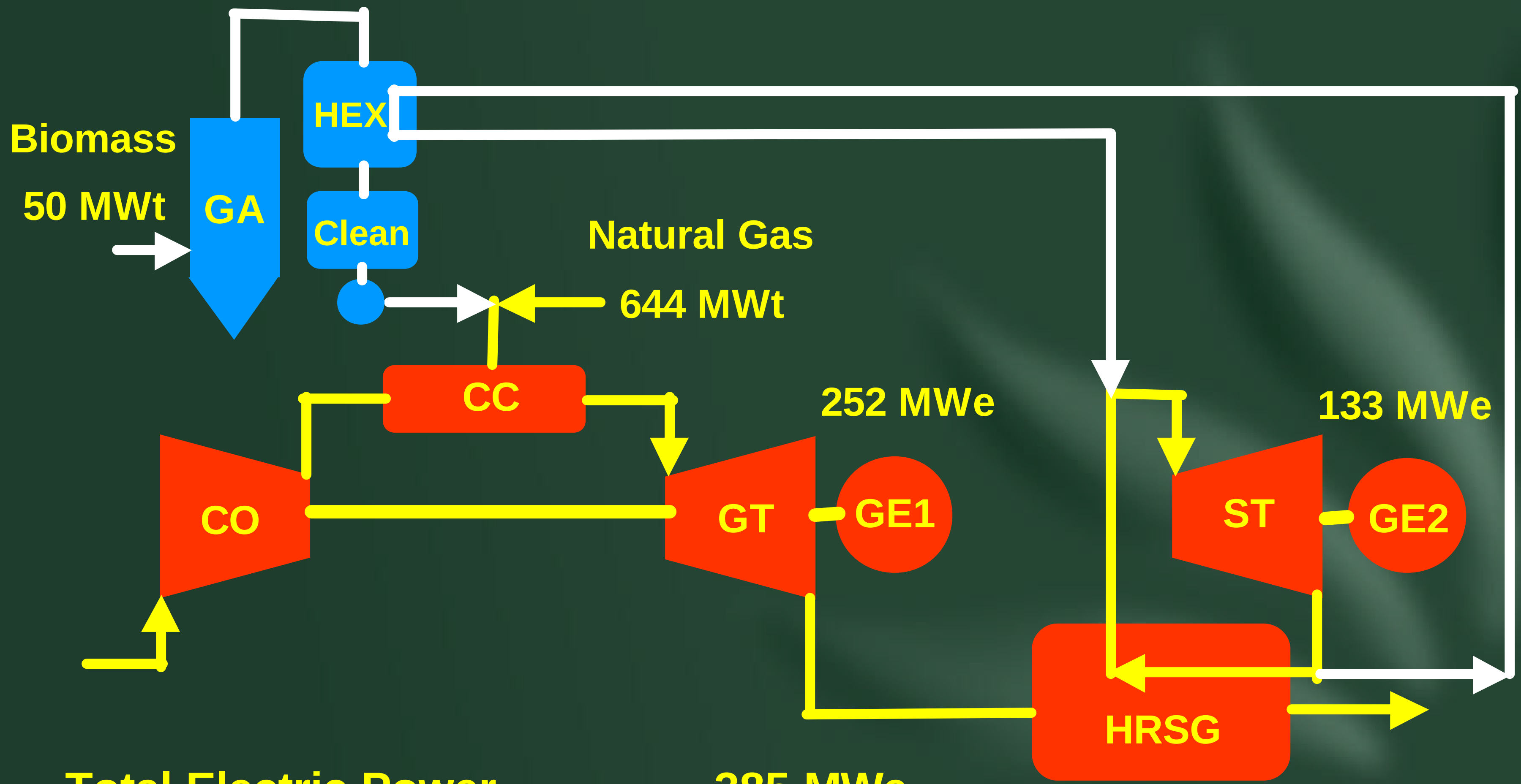
Reference Plant

- Combined Cycle Power 380 MWe
- Net Cycle Efficiency 56.5 %

Plant Retrofit Configurations

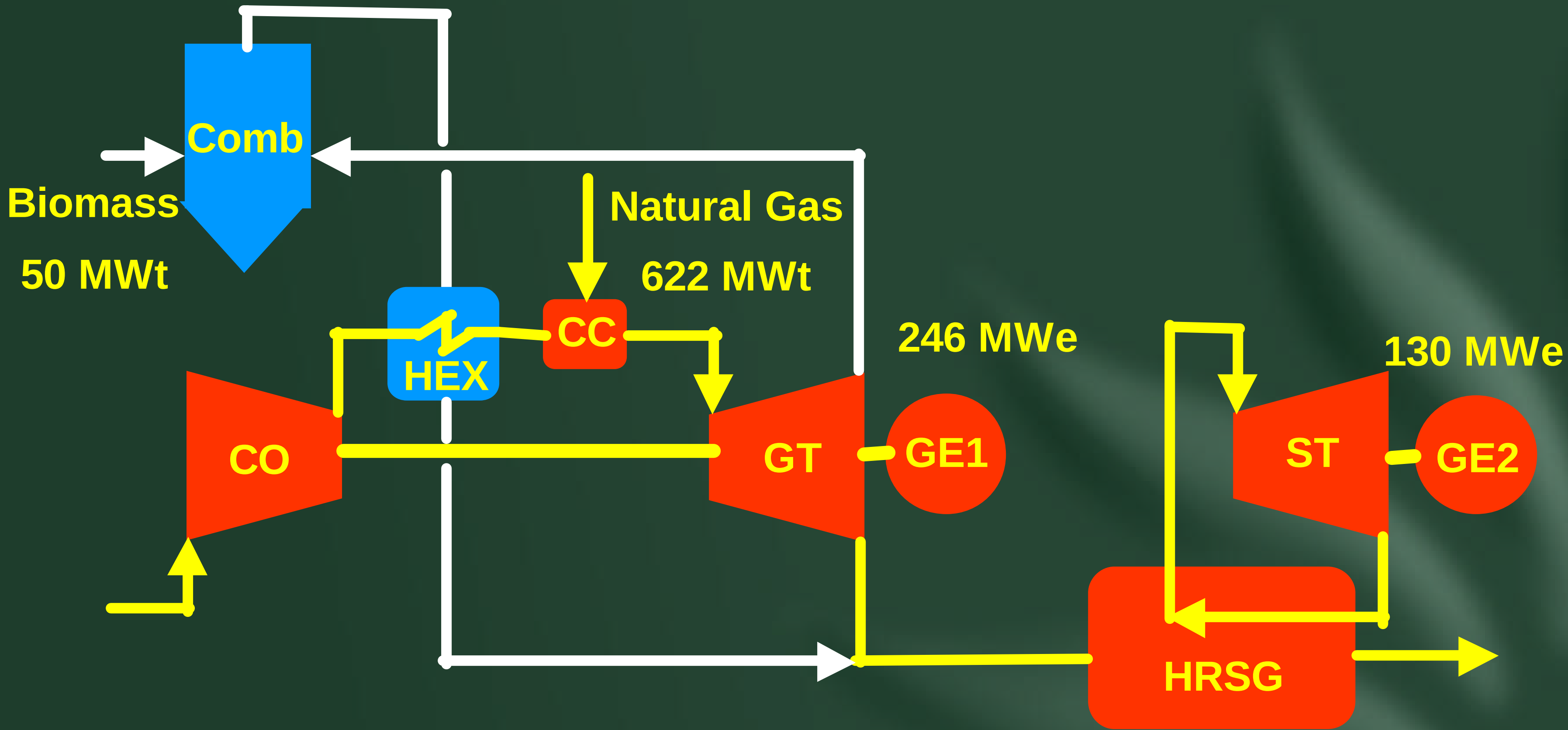
- Biomass gasification and biogas co-firing in the gas turbine
- External combustion of biomass and air preheating in the gas turbine
- Biomass gasification and biogas additional-firing in the Heat Recovery Steam Generator (HRSG)

1. Biogas Co-firing in Gas Turbine



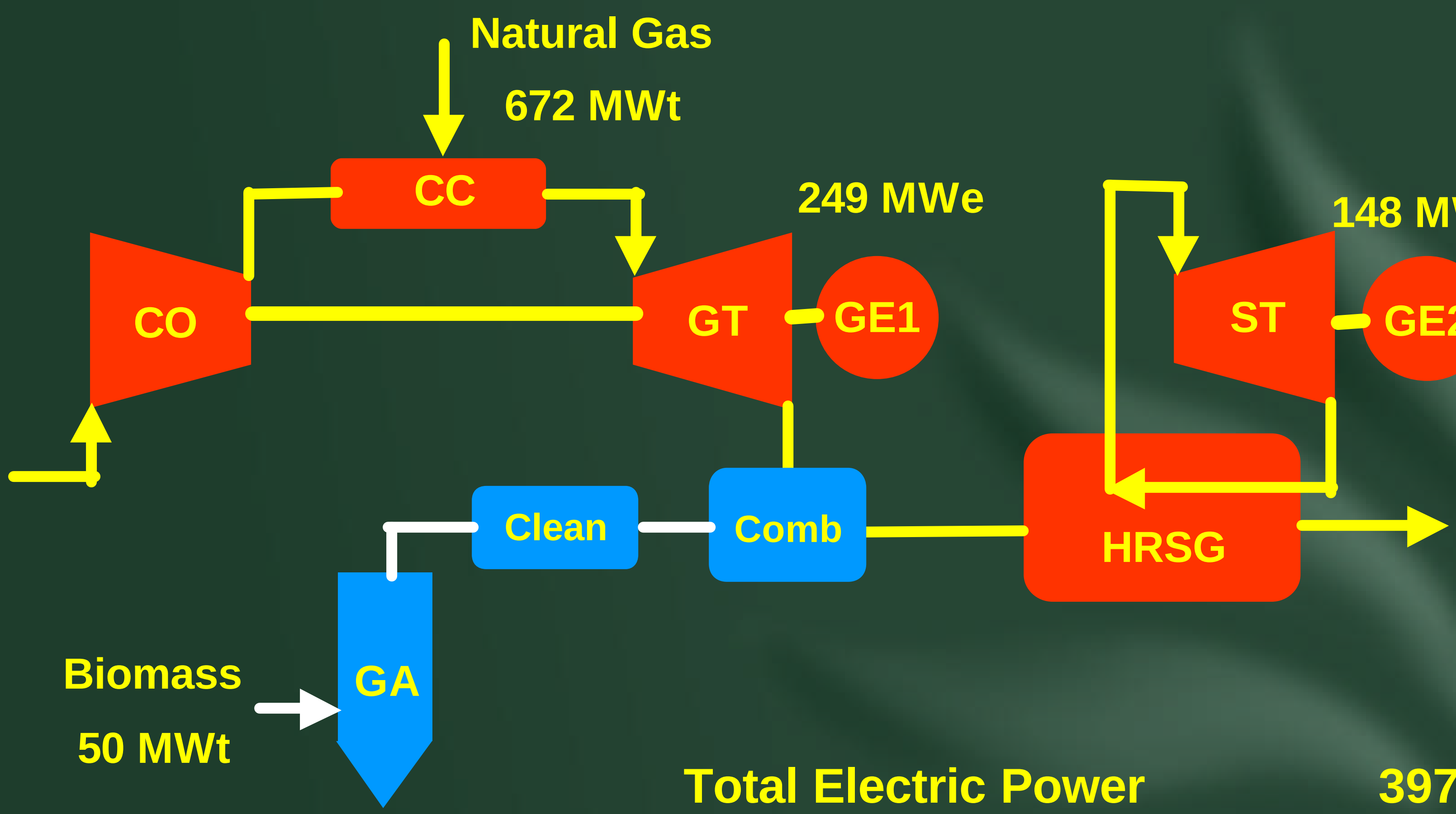
Total Electric Power	**385 MWe**
Total Net Efficiency	**55.5 %**

2. External Biomass Combustion



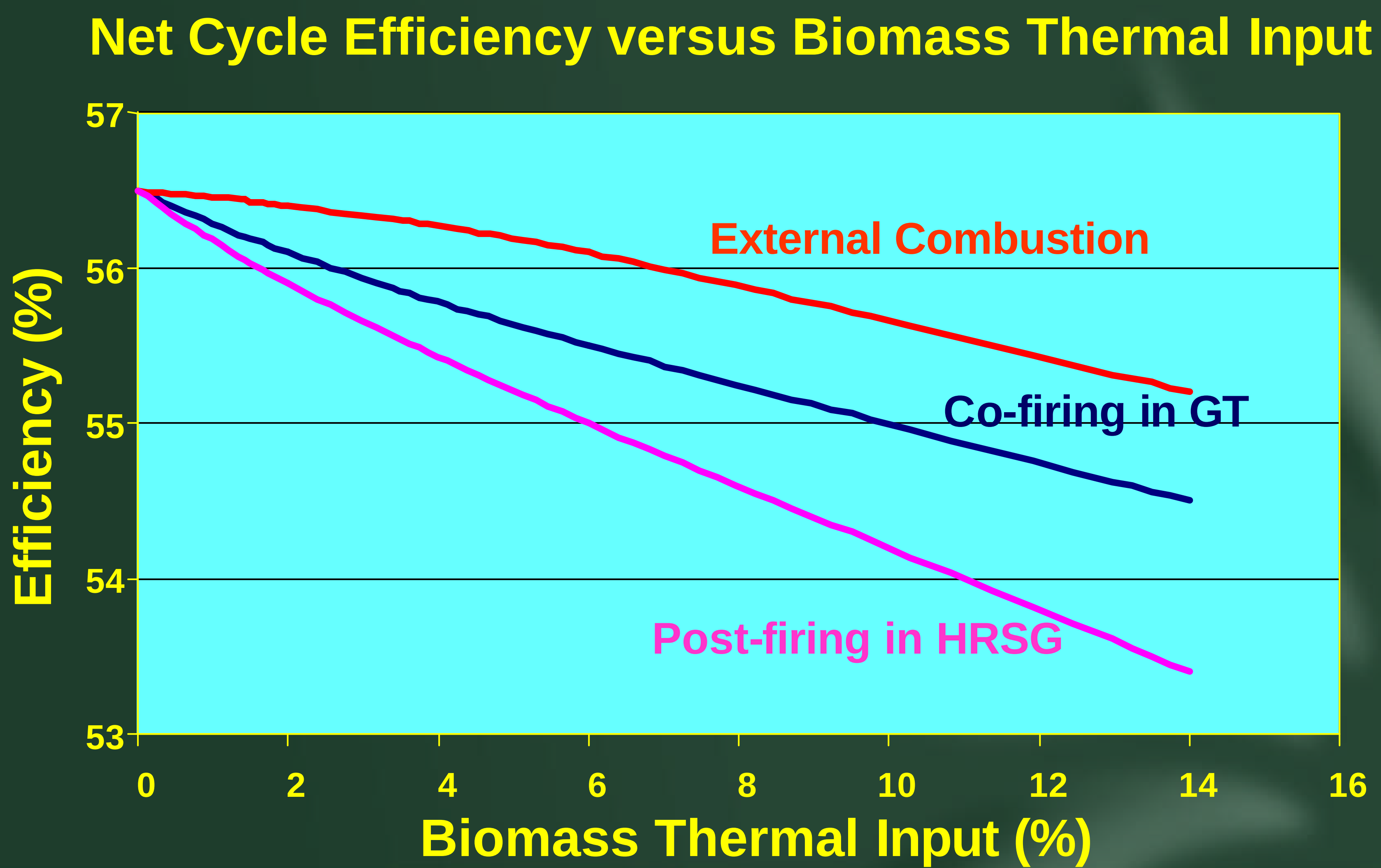
Total Electric Power **376 MWe**
Total Net Efficiency **55.9 %**

3. Biomass Post-firing in HRSG

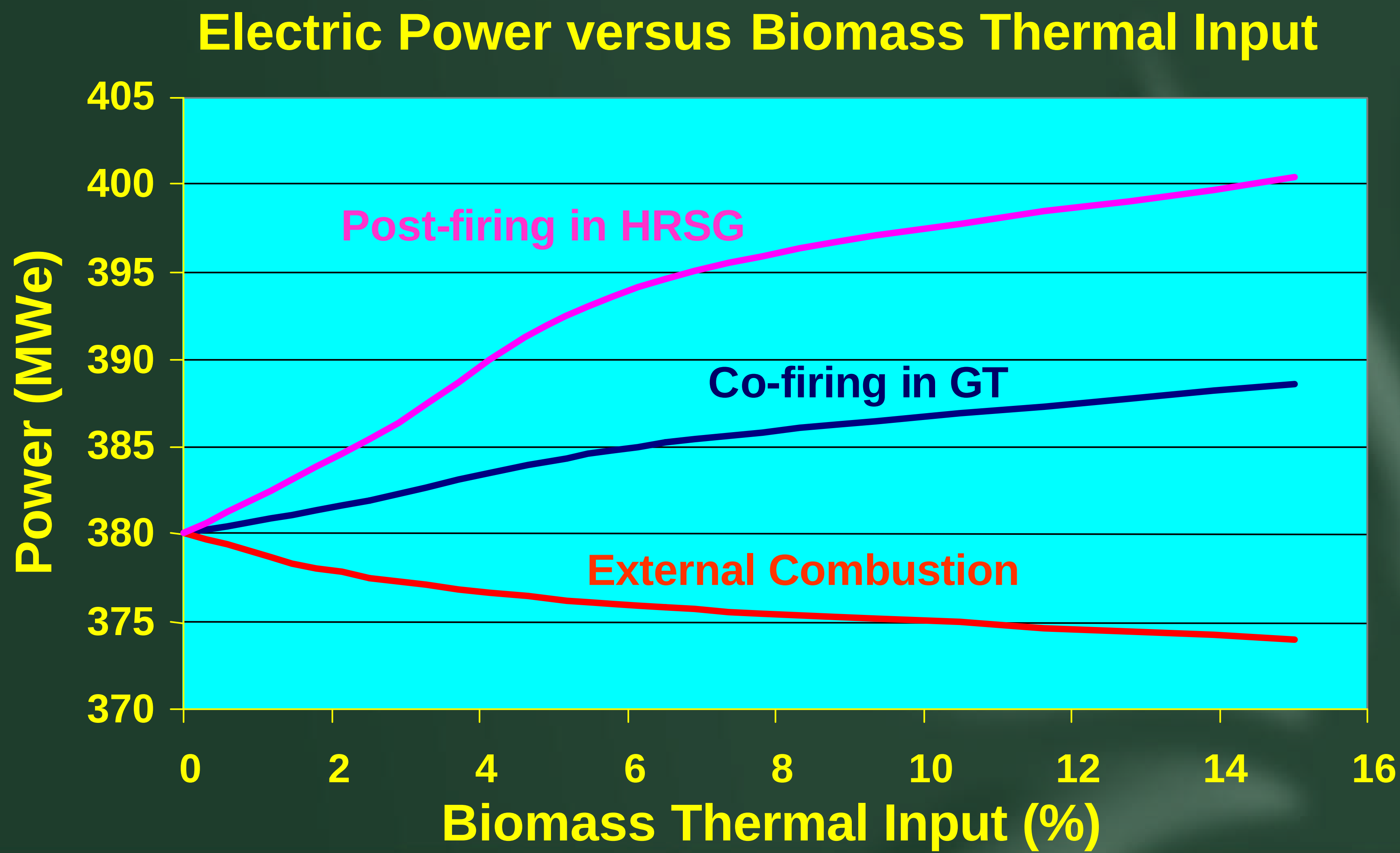


Total Electric Power **397 MWe**
Total Net Efficiency **55 %**

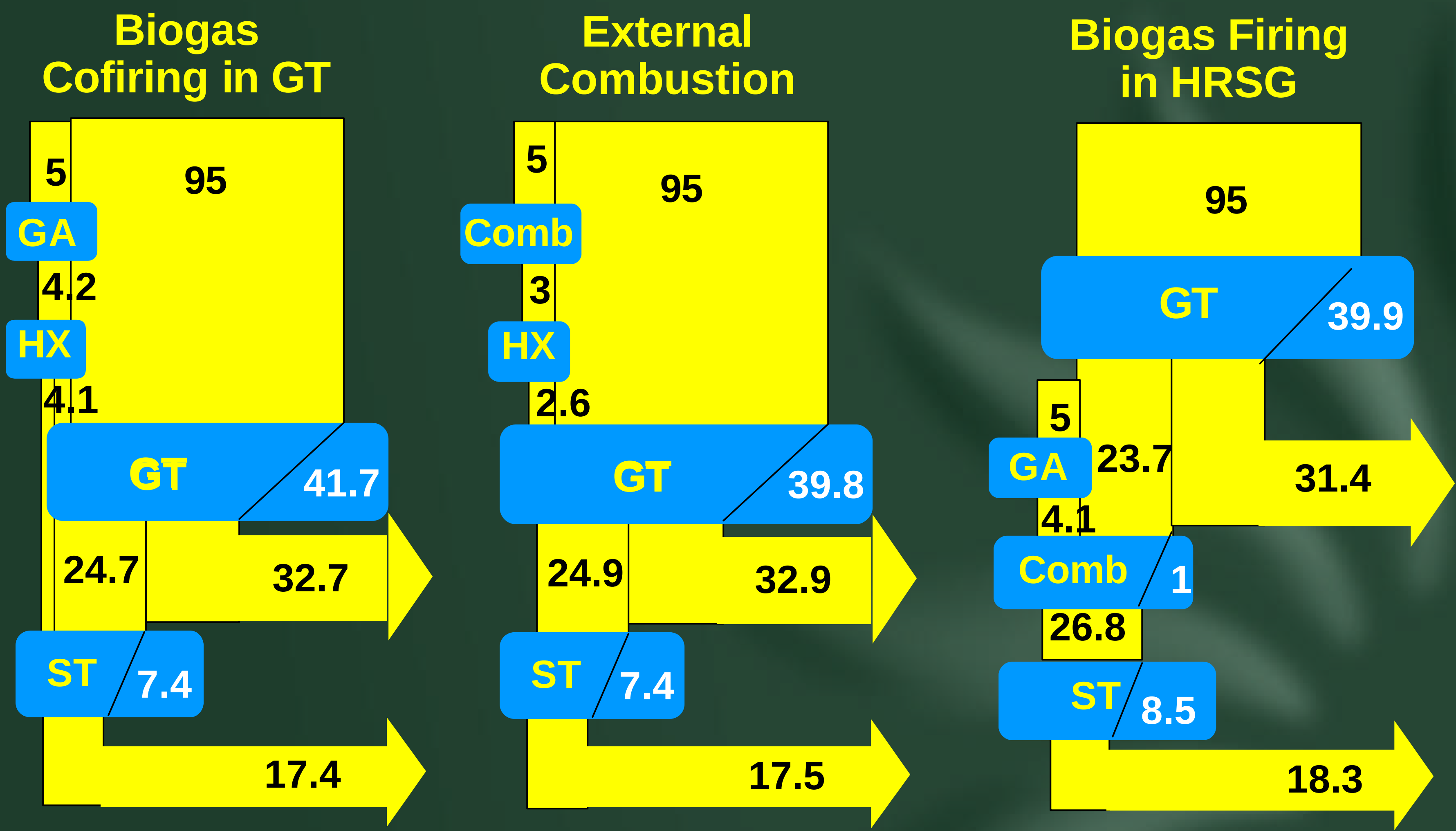
Comparision between the performances



Comparision between performances



Exergetic Analysis



Exergetic Analysis

- **The best performances can be achieved when biomass power is introduced in the top cycle (gas turbine)**
- **External combustion allows the most efficient integration; in fact the reduction of irreversibility in the gas turbine fully compensates the irreversibility losses in biomass combustion**
- **Biogas co-firing in the HRSG is the least efficient configuration, since biomass is utilised at a low thermal level, but it allows additional power to be produced by the steam cycle**

Economical Analysis

Evaluations consider additional costs and incomes of the three solutions with respect to the reference NGCC

Input data:

• Biomass Input	50 MWt
• Equivalent annual operation at full load	6500 h
• Time for construction	2 years
• Annual O&M (% of capital cost)	3 %
• Annual discount rate	8 %
• Life of the project	8 years
• Taxes	41.25 %
• Natural Gas price	0.5 cE/MJ
• Biomass price	0.31 cE/MJ
• Electricity price	4.3 cE/kWh
• Green certificate price	5.8 cE/kWh

Economical Analysis

Biomass Conversion Efficiency

$$\left(W_{t,bio} + W_{t,NG}\right) \cdot ?_{tot} = W_{t,bio} ?_{bio} + W_{t,NG} ?_{CC,ref}$$

$$?_{bio} = ?_{tot} - \frac{W_{t,NG}}{W_{t,bio}}\left(?_{CC,ref} - ?_{tot}\right)$$

Results

- Biomass gasification and co-firing in GT	44 %
- Biomass external combustion	48 %
- Biomass gasification and firing in HRSG	35 %

Economical Analysis

Investment Costs (Meuro)

	Biogas Cofiring in GT	External Combustion	Biogas Firing in HRSG
• Biomass storage	2.5	2.5	2.5
• Syngas gasif./cleaning	25.0	-	22.5
• Syngas compressor	2.5	-	-
• Biomass burner	-	5.0	-
• Gas-air heat exchanger	-	5.0	-
• Exhaust gas filter	-	7.5	-
Total Investment	**30.0**	**20.0**	**25.0**

Results of economical analysis

	Biomass Conversion Efficiency (%)	Investment Cost (ME)	O&M Cost (ME/Y)	Fuel Cost (ME/Y)	Income (ME/Y)	Gross Cash Flow (ME/Y)	NPV (ME)	IRR (%)
Biogas Cofiring in GT	44	30	0.9	0.05	10	8.8	3.1	10.3
External Combustion	48	20	0.6	-2.6	7.7	9.6	21.8	20.2
Biogas Firing in HRSG	35	25	0.75	3.3	11.3	7.2	2.4	10.1

Conclusions

Advantages		Disadvantages
• High conversion efficiency • Slight increase of electric power	**Cofiring in GT**	• High installation cost
• Highest conversion efficiency	**External Combustion**	• High tech. risk • Slight decrease of electric power
• Significative increase of electric power	**Add.Firing in HRSG**	• Low conversion efficiency

Conclusions

- The most promising solution is the external combustion both in terms of conversion efficiency than in terms of economics, but unfortunally it is the less industrially tested and technologically critic for for the presence of the gas-air heat exchanger
- Syngas cofiring in the gas turbine results in a good conversion efficiency, but it is jet penalized by the cost of gassification and syngas cleaning
- Syngas cofiring in the heat recovery boiler is less interesting for the relatively low efficiency, similar to the ones tipical of direct biomass cofiring in convenctional steam units
- Concluding, the integration of biomass in combined cycle cannot yet be considered an industrially assessed technology and requires further investigations in the fields of thermodynamics, processes and components.